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(71) Applicant
United Kingdom Atomic Energy Authority

(Incorporated in United Kingdom)

11 Charles II Street, London, SW1Y 4QP

(72) Inventors
Brian Michael Hawker
Ronald Sydney Green

(74) Agent and/or Address for Service
Peter Turquand Mansfield
Patents Branch,
United Kingdom Atomic Energy Authority,
11 Charles II Street, London, SW1Y 4QP

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G1G
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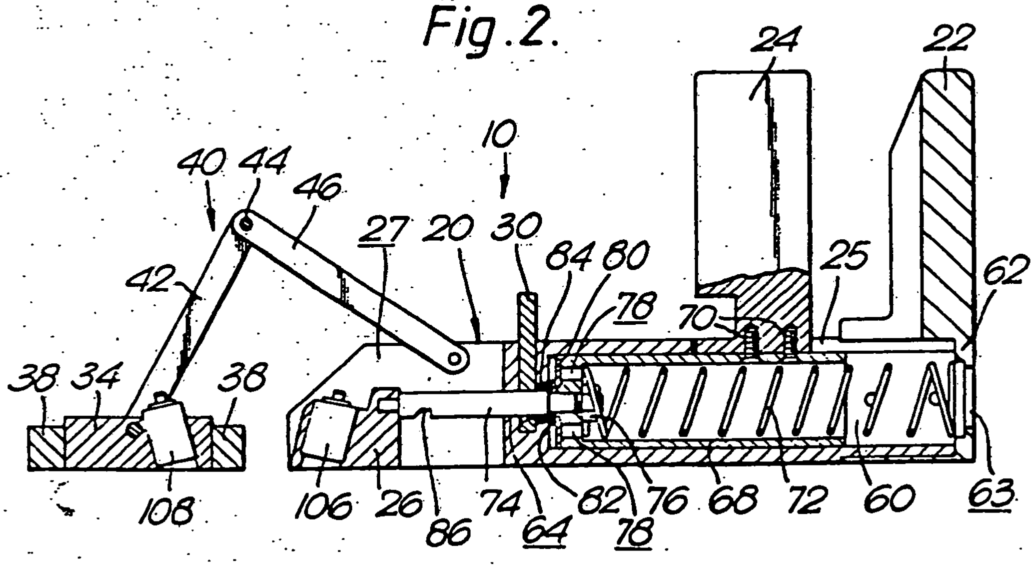
(54) Ultrasonic scanning apparatus

(57) Apparatus (10) is provided for performing time-of-flight diffraction (TOFD) inspection of an under-water object such as an oil-well platform, including means (34, 40, 20) to support two ultrasonic transducers (106, 108) adjacent to the surface of the object but spaced apart from each other, and means (24, 72) to cause one transducer (106) to slide along the surface towards the other transducer (108). A slow speed of about 5 mm/sec is achieved by using the water to damp the sliding motion. The apparatus can be used to size cracks at a welded joint between two members.

Fig. 2.



The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

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Fig.1.

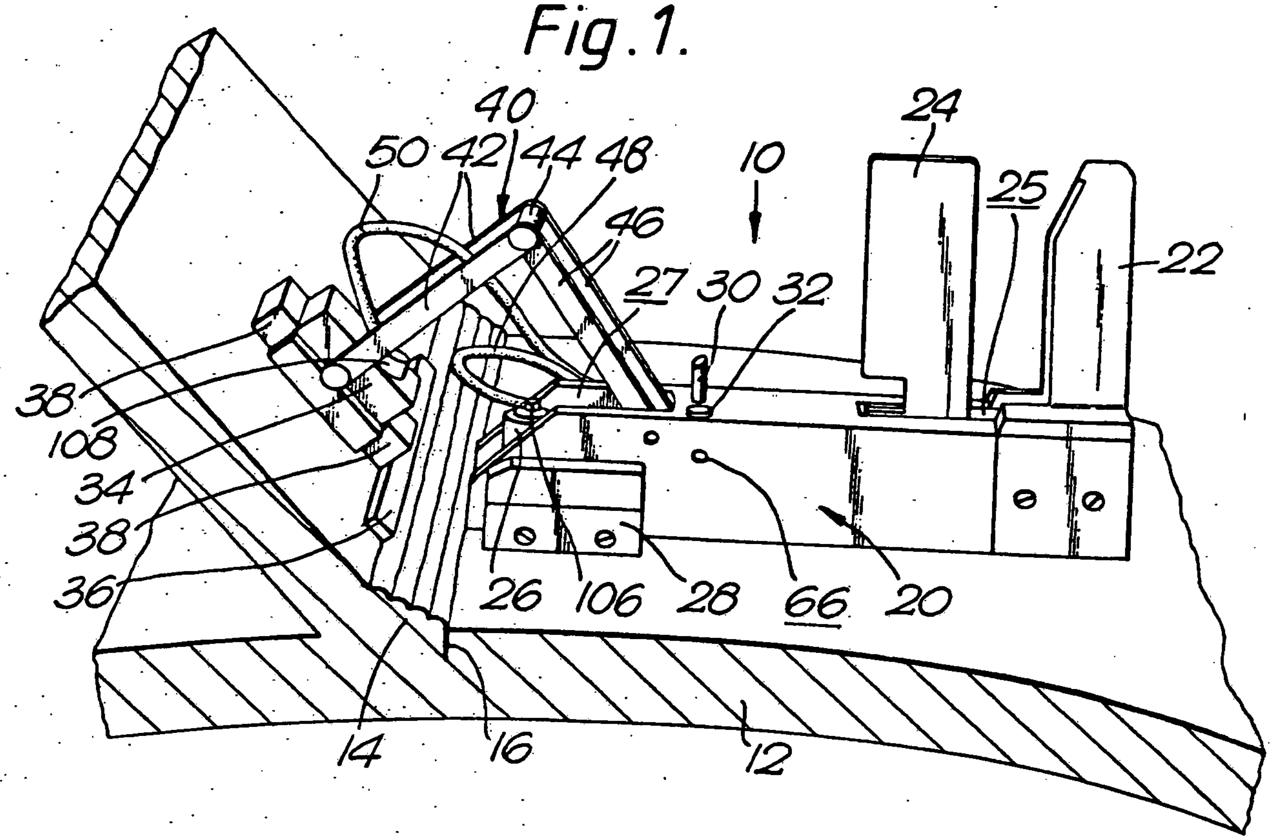

40
50 42 44 48
10
24
25
22
46
27 30 32
38
108
34
38
36
26 106 28 66 20
14 16 12

Fig.2.

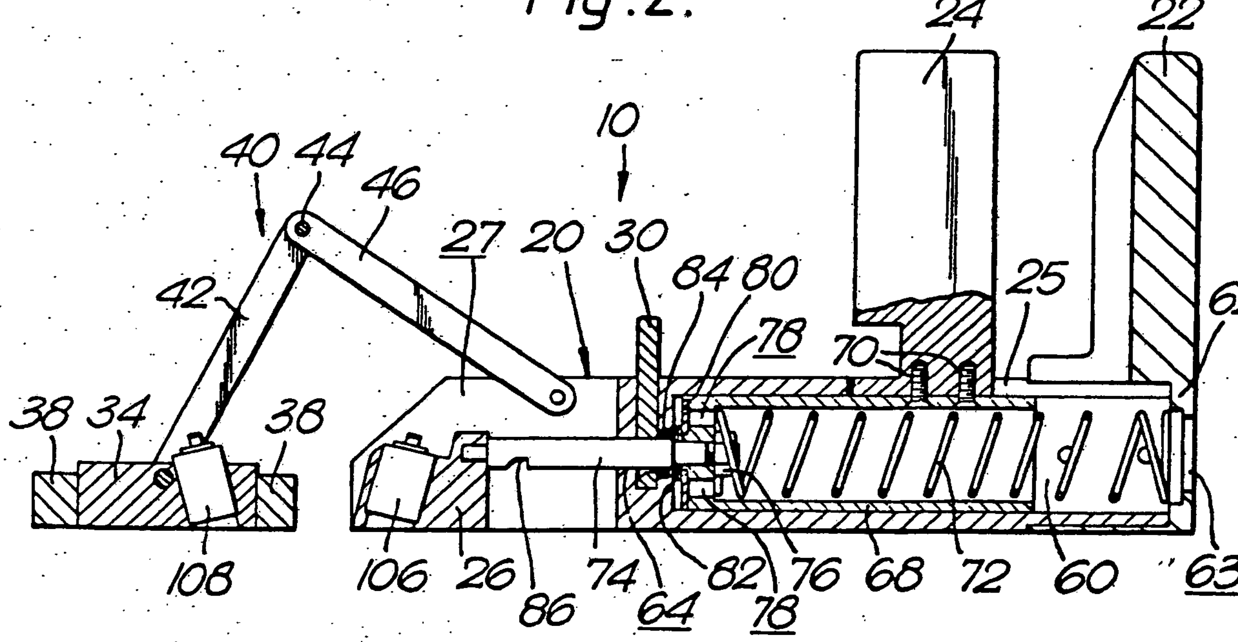

24 22
10
40 44 46
27 20 30 84 80 25 62
42
78 70
38 34 38
108 106 26 86 74 64 82 78 76 68 72 60 63

Fig. 3.

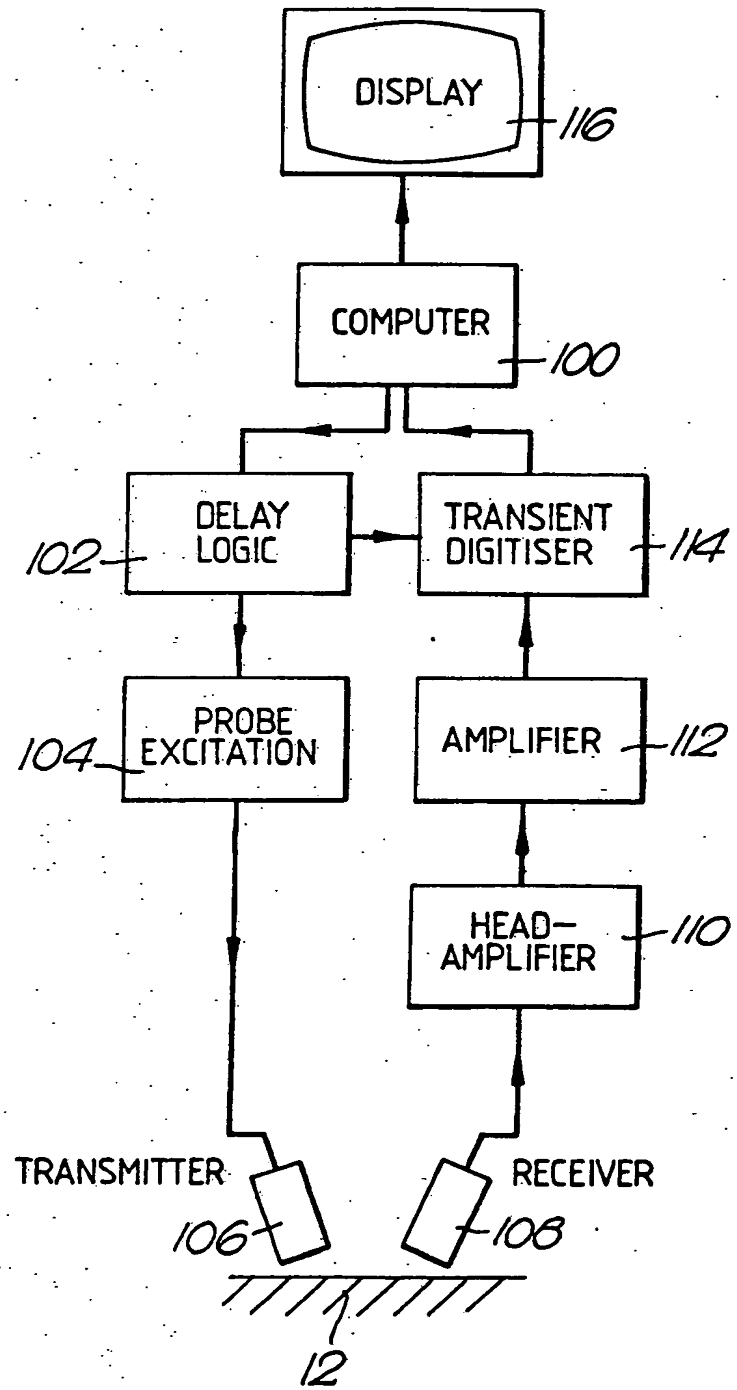

DISPLAY
116
COMPUTER
100
DELAY LOGIC
102
TRANSIENT DIGITISER
114
PROBE EXCITATION
104
AMPLIFIER
112
HEAD-AMPLIFIER
110
TRANSMITTER
106
RECEIVER
108
12

Fig. 4.

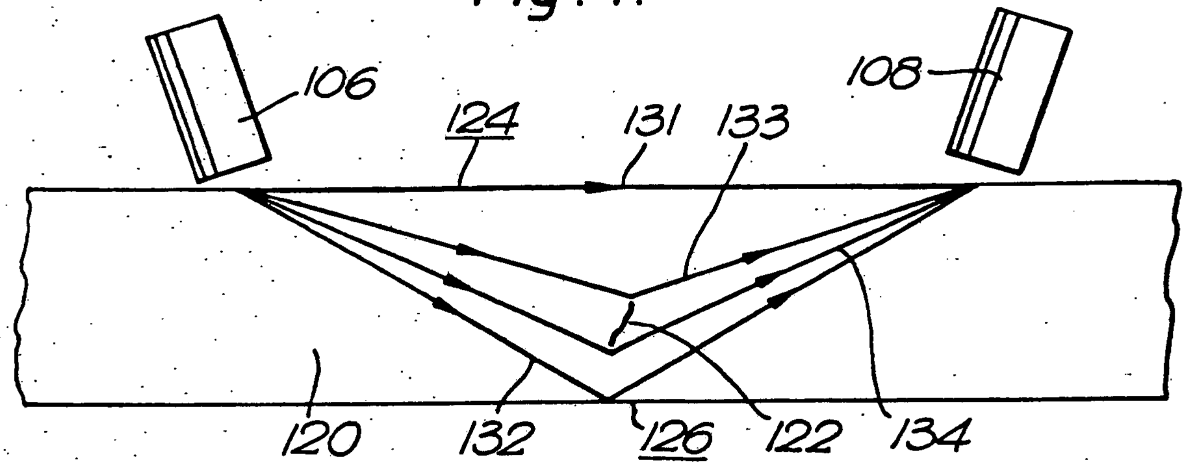
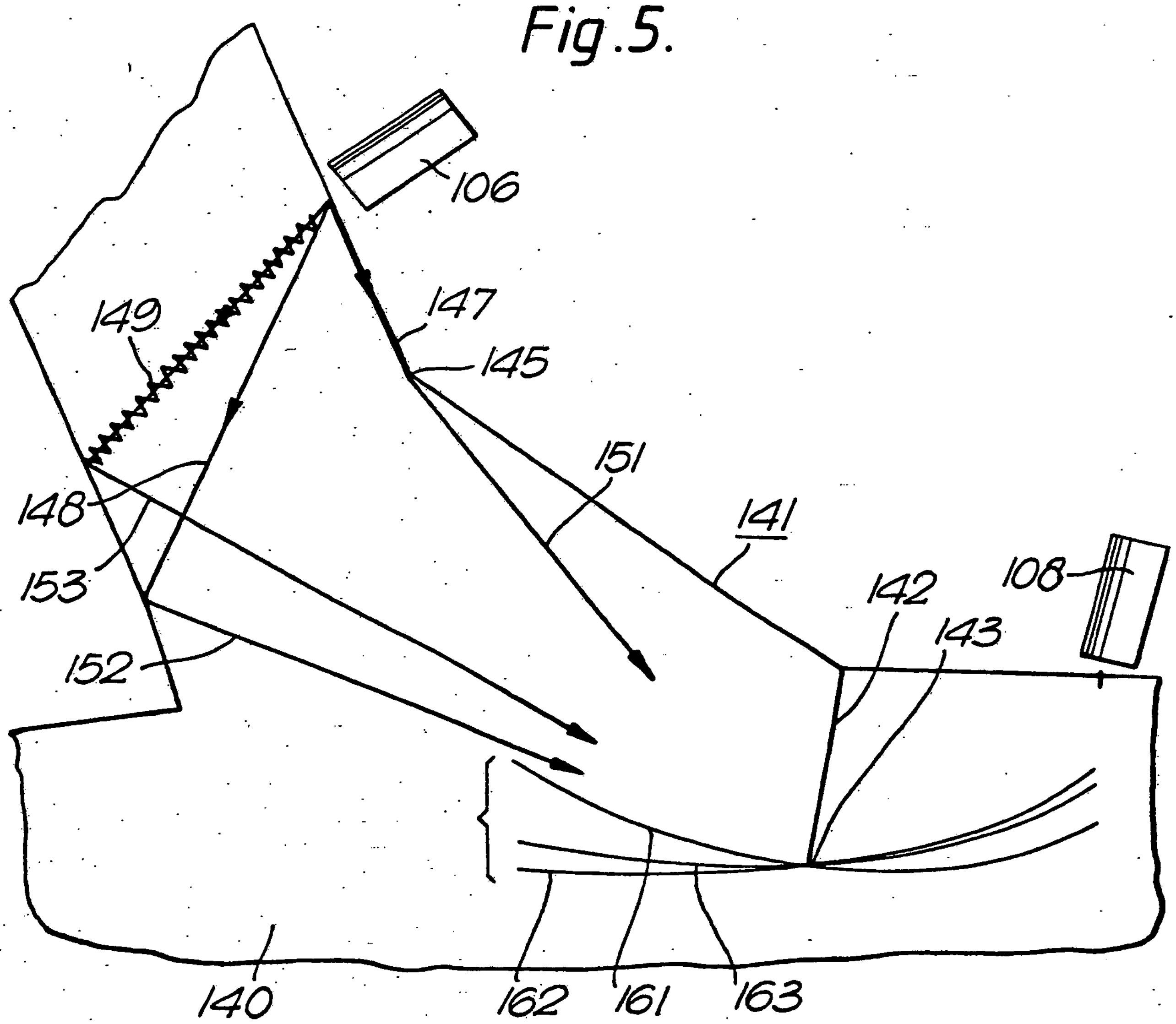

106
108
124
131
133
120
132
126
122
134

Fig. 5.


106
149
147
145
151
141
148
153
152
142
143
108
140
162
161
163

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Ultrasonic Scanning Apparatus

This invention relates to an apparatus and a method for performing ultrasonic inspection of objects, and in particular to apparatus for performing ultrasonic time-of-flight diffraction (TOFD) inspection of under-water objects.

For the inspection of under-water objects such as oil-well platforms ultrasonic techniques can be used, and the water itself provides a couplant for ultrasonic waves. It may be necessary to clean the surface of the object first, to remove for example corrosion products, calcereous deposits, or organic growths. If ultrasonic inspection is to be carried out by a diver it is advantageous to minimize the complexity of the apparatus and to simplify its mode of operation, as the diver may not have both hands free, and may be made clumsy by his diving suit.

According to the present invention there is provided an apparatus for performing ultrasonic time-of-flight diffraction (TOFD) inspection of an object immersed in water, the apparatus comprising a frame for placing on a surface of the object, a first probe carrier slidable in a straight line along the frame, resilient means for urging the first probe carrier to undergo such sliding motion, means for initiating the sliding motion, and damping means utilizing the water to oppose the sliding motion; a second probe carrier connected to the frame such that the second probe carrier can be placed on the surface spaced apart from the first probe carrier but on the said straight line; and two ultrasonic transducers, supported respectively by the first and the second probe carriers.

Preferably the frame and the second probe carrier both incorporate means, such as permanent magnets, to hold them

in desired positions on the surface.

Preferably the means connecting the second probe carrier to the frame includes at least one hinge so that the frame and the second probe carrier can be against portions of the surface having different orientations, for example on different members welded together.

Desirably means are provided to adjust the degree of damping. In the preferred embodiment the damping means comprises a piston movable in a water-filled cylinder, movement of the piston causing the water to pass through an aperture of restricted size. The piston may incorporate a one-way valve so that motion in the reverse direction is not significantly opposed. The desired motion of the first probe carrier is a straight line motion through about 40 mm in a time of about 8 seconds.

The invention will now be further described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 shows a perspective view of an inspection apparatus of the invention;

Figure 2 shows a longitudinal sectional view through the apparatus of Figure 1;

Figure 3 shows a block diagram of electronic circuitry for use with the apparatus of Figure 1;

Figure 4 shows diagrammatically some wave paths in a cracked object during TOFD inspection; and

Figure 5 shows diagrammatically some wave paths in another cracked object during TOFD inspection.

Referring to Figure 1 there is shown a TOFD inspection appartus 10, located on an under-water structure 12 (only a part of which is shown) including a weld 14 in which a crack 16 in suspected. The apparatus 10 comprises a body or frame 20 with a handle 22 at one end, and a priming handle 24 slidable along a slot 25 in the body 20 and connected to a probe carrier 26 at the other end of the body 20 slidable in a slot 27. The body 20 is placed square to the line of the weld 14, with its front edge adjacent the edge of the weld 14, and is held firm in that position by two permanent magnets 28 (only one is shown), one on each side of the body 20. On the upper surface of the body 20 are a trigger 30 and a speed adjusting knob 32 whose operation is described later.

A second probe carrier 34 is placed on the surface of the structure 12 the other side of the weld 14, spaced apart from the edge of the weld 14 by a magnetic strip 36 laid along the surface, and is held in position by two permanent magnets 38. The probe carrier 34 is connected to the body 20 by a hinge mechanism 40 which ensures the probe carrier 34 is always aligned with the slot 27. The mechanism 40 comprises two parallel strips 42 pivotally connected to opposite sides of the carrier 34 and, at their other end, connected by a hinge pin 44; and two parallel strips 46 pivotally connected to the body 20 on opposite sides of the slot 27, and at their other end connected to the hinge pin 44. Cables 48 and 50 are connected to ultrasonic transducers 106 and 108 carried by the probe carriers 26 and 34.

Referring now to Figure 2, the body 20 defines a cylindrical bore 60, open at its right-hand end (as shown), a cylindrical portion 62 of the handle 22 being fixed over the open end of the bore 60 and defining a port 63 of smaller diameter than the bore 60. The bore 60 is closed

at its left-hand end (as shown), except for an axial hole 64 which extends through to the slot 27, and for a radially extending narrow leakage hole 66 (shown in Figure 1) flow through which is restricted by a screw turned by the speed adjusting knob 32 (shown in Figure 1). Within the bore 60 is a tubular cylindrical piston 68, open at its right hand end and closed at its left hand end. The piston 68 is joined by screws 70 to the priming handle 24. A compression spring 72 is located within the piston 68 and extends to the end of the bore 60 to abut the handle portion 62; the spring 72 urges the piston 68 towards the closed end of the bore 60.

A rod 74 extends through the axial hole 64, and at one end is joined to the probe carrier 26. At the other end of the rod 74, a portion of slightly smaller diameter is threaded, and is fixed by a nut 76 through the closed end of the piston 68. Two valve holes 78 extend through the closed end of the piston 68 and are covered by an annular rubber diaphragm 80 clamped around its inner edge by a washer 82, the washer 82 being clamped between the end of the piston 68 and the step in diameter of the rod 74. An O-ring seal 84 prevents water flowing through the axial hole 64 along the side of the rod 74.

In operation of the apparatus 10 for inspection of an underwater structure it will be appreciated that the bore 60 will be full of water, which can freely enter through the port 63. The priming handle 24 is first pulled back by an operator, so pulling back the piston 68, the rod 74 and the probe carrier 26. The diaphragm 80 acts as a flap valve, allowing water to flow through the valve holes 78 to the other side of the piston 68. The trigger 30 can then slide up to engage with a notch 86 on the rod 74. When it is desired to perform an ultrasonic scan, the trigger 30 is depressed by the operator, releasing the rod 74. The

piston 68 is pushed forward by the spring 72, though because water in the space between the end of the piston 68 and the closed end of the bore 60 can only leave through the leakage hole 66, the motion of the piston 68 and hence of the probe carrier 26 is comparatively slow. Typically the probe carrier 26 moves forward 40 mm in a time of about 8 seconds - this time may be adjusted by turning the speed adjusting knob 32.

The two probe carriers 26 and 34 as mentioned above locate two identical ultrasonic transducers, 106 and 108 respectively, which are inclined to the vertical. The carriers 26 and 84 are of ultrasonically absorbent plastic such as polyethylene to shield the transducers 106 and 108 from stray signals. Each transducer 106 and 108 has an active face of diameter 6.35 mm. In the description below transducer 106 is described as the transmitting transducer and transducer 108 as the receiving transducer, but it should be understood that these roles may equally well be reversed.

The transmitting transducer 106 is arranged, when energised, to transmit a brief pulse of ultrasonic compression waves of frequency 10 MHz and of duration about two cycles, which are coupled by the surrounding water into an object under inspection (such as the structure 12 of Figure 1). The receiving transducer 108 is spaced apart from the transducer 106 along the surface of the object, and is arranged to detect ultrasonic waves which have propagated through the object. The transducer 106 is inclined to the normal at such an angle to generate 10 MHz compression waves at 65° to the normal within the object; the pulse is so brief however that waves are generated over a broad frequency range, the lower frequency waves (down to about 2 MHz) energing as a divergent beam, extending from about 55° to the normal to along the surface

itself, within the object. Shear waves are also generated in the object, propagating closer to the normal.

Referring to Figure 3 there is shown, as a block diagram, the electronic circuitry used with the inspection apparatus of Figure 1. Operation of the circuitry is controlled by a computer 100. The computer 100 is connected via a delay module 102 to a probe excitation circuit 104, connected to the transmitting transducer 106. The receiving transducer 108 is also connected to the computer 100 via a head amplifier 110, an amplifier 112, and a transient digitizer 114. In addition, a display screen 116 is connected to the computer 100.

The computer 100 initiates ultrasonic operations at a rate of 400 Hz; on each occasion the delay module 102 is triggered and the excitation circuit 104 simultaneously excites the transducer 106 to produce a brief pulse of ultrasonic compression waves. These compression waves are coupled by the surrounding water into a structure 120, propagate therein as described below, and are received by the transducer 108. The corresponding electrical signals are amplified by the head amplifier 110 and the amplifier 112 and impedance-matched to the digitiser 114. The digitiser 114 is controlled by the delay module 102 to commence operation at a pre-set time after excitation of the transducer 106, and digitises the amplified signals at a frequency of at least 20 MHz. To achieve an adequate signal-to-noise ratio the computer 100 then averages groups of thirty-two successive signal transients received from the digitiser 114, and these averaged transients are stored, and can be displayed either in A-scan or B-scan format on the display screen 116.

In operation of the apparatus 10 of Figure 1 in conjunction with the circuitry of Figure 3, the sliding

motion of the probe carrier 26 typically lasts eight seconds. In this time the transmitting transducer will be excited three thousand two hundred times, and the computer 100 will therefore generate one hundred averaged transients, for display in B-scan format. In general, ultrasonic waves which have traversed the thickness of the structure under investigation twice, being reflected from the rear surface, before being received will produce a comparatively large transient signal, at a time which depends upon the separation of the two transducers. When the signals are displayed in B-scan format, the speed of the sliding motion can be inferred from the slope of the B-scan feature representing this rear surface reflection signal.

The apparatus 10 of Figure 1 in conjunction with the circuitry of Figure 3 can be used to inspect objects of a wide variety of shapes. Referring to Figure 4, some of the wave paths are shown for a parallel-sided steel sheet 120 with a buried crack 122. In this situation there are four ways in which the transducer 108 receives ultrasonic waves. Firstly, a compression wave (a lateral wave) 131 propagates along the front surface 124. Secondly, a compression wave 132 reflects off the rear surface 126 of the object 120. Thirdly and fourthly, compression waves incident on the crack 122 are diffracted in all directions by each end of the crack 122; diffracted waves 133 and 134 propagate towards the transducer 108. Since the velocity of ultrasonic compression waves in steel is known, measurement of the time, after energising the transducer 106, at which the two diffracted waves 133 and 134 are received determines the total distance travelled by (i.e. the path length for) the two waves 133 and 134. Such a distance defines an elliptical locus with the transducers 106 and 108 as foci, on which the respective crack tip must lie. By repeating the measurements with one or both transducers

106 and 108 in different positions in the same plane, a second elliptical locus is defined for each crack tip, and the point of intersection of the two corresponding loci determines the location of the tip of the crack 122. Thus the method enables the position, orientation and size of the crack 122 to be determined.

TOFD inspection is also applicable to objects of more complex shapes, and in Figure 5 to which reference is now made there are shown some of the wave paths in a steel object 140 (of similar shape to the structure 12 of Figure 1), with a surface-breaking crack 142. Transducers 106 and 108 are arranged spaced apart from each other along one surface 141 of the object 140 on opposite sides of the crack 142. The tip 143 of the crack 142 is at such a position that no waves coming straight from the transducer 106 through the object 140 can reach it. Nevertheless there are three ways in which waves can reach the crack tip 143 to be diffracted and hence reach the transducer 108.

Firstly the lateral compression wave 147 is diffracted at a corner 145, and a diffracted wave 151 propagates towards the crack tip 143. Secondly a compression wave 148 is reflected from a rear surface 150 of the object 140 so a reflected compression wave 152 propagates towards the crack tip 143. Thirdly, a shear wave 149 is partially mode-converted to a compression wave 153 and reflected at the rear surface 150 (this process obeying Snell's Law) which propagates towards the crack tip 143. Thus three compression waves 151, 152 and 153 are incident on the crack tip 143 at different times, each being diffracted by the crack tip 143 and so detected by the transducer 108. The times of arrival of these diffracted waves determine three elliptical loci 161, 162, 163 on which the crack tip 143 must lie. For each locus one focus is at the

transducer 108; for the locus 161 corresponding to the diffracted wave 151 the other focus is at the corner 145; for loci 162 and 163 corresponding to the reflected waves 152 and 153 the other foci are at the respective mirror images of the transducer 106, from which the waves 152 and 153 appear to come.

It will be appreciated that the TOFD inspection technique is applicable to objects with surface roughness, as signal amplitude fluctuations due to changes in coupling do not affect the results, as only the arrival time of the ultrasonic waves is relevant. Furthermore it has been found capable of measuring the depth of crack tips below the surface to an accuracy of about 1 mm for cracks more than 5 mm below the surface. However shallow cracks extending less than about 5 mm below the surface cannot reliably be detected.

Claims

1. An apparatus for performing ultrasonic time-of-flight diffraction (TOFD) inspection of an object immersed in water, the apparatus comprising a frame for placing on a surface of the object, a first probe carrier slidable in a straight line along the frame, resilient means for urging the first probe carrier to undergo such sliding motion, means for initiating the sliding motion, and damping means utilizing the water to oppose the sliding motion; a second probe carrier connected to the frame such that the second probe carrier can be placed on the surface spaced apart from the first probe carrier but on the said straight line; and two ultrasonic transducers, supported respectively by the first and the second probe carriers.

2. An apparatus as claimed in Claim 1 wherein both the frame and the second probe carrier incorporate means to hold them in desired positions on the surface.

3. An apparatus as claimed in Claim 1 or Claim 2 wherein the means connecting the second probe carrier to the frame includes at least one hinge such that the frame and the second probe carrier can be against portions of the surface having different orientations.

4. An apparatus as claimed in any one of the preceding Claims also including means to adjust the degree of damping.

5. An apparatus as claimed in any one of the preceding Claims wherein the damping means comprises a piston movable in a water-filled cylinder, arranged such that movement of the piston causes water to pass through an aperture of restricted size.

6. An apparatus as claimed in any one of the preceding Claims wherein the damping means is arranged so as to oppose the sliding motion of the first probe carrier in one direction, but to provide much less opposition to motion of the first probe carrier in the reverse direction.

7. An apparatus, for performing ultrasonic time-of-flight diffraction inspection of an object immersed in water, substantially as hereinbefore described with reference to, and as shown in, Figures 1 and 2 of the accompanying drawings.

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